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Teaching nanoscience across scientific and geographical borders - A European Master programme in nanoscience and nanotechnology.

A Chesneau[1], G Groeseneken[2], P Heremans[2], D Rep[3], P Rudquist[6], P Schwille[1], B Sluijter[4,5], and G Wendin[6]

[1] Institute of Biophysics, TU Dresden, Dresden, Germany
[2] E.E. department of the Katholieke Universiteit Leuven, IMEC, Leuven, Belgium
[3] Delft University of Technology, Delft, The Netherlands
[4] Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands
[5] Leiden Institute of Physics, Leiden University, Leiden, The Netherlands
[6] MC2, Chalmers University of Technology, Gothenburg, Sweden

E-mail: per.rudquist@mc2.chalmers.se,goran.wendin@mc2.chalmers.se

Abstract. Within the Erasmus Mundus Master (EMM) Programme, five European Universities (KU Leuven, Belgium, Chalmers University of Technology, Sweden, Delft University of Technology and Leiden University, the Netherlands, and the University of Dresden, Germany) have joined forces to offer a unique master programme in Nanoscience and Nanotechnology," EMM-nano", at the cutting edge of state-of-the-art research. The students design and build their individual area of specialisation within nanophysics, nanotechnology, biophysics, biotechnology through their choice of trajectory between the partners. We discuss some of the challenges related to the crossdisciplinary nature of the field, educational activities in cleanrooms, and issues related to the integration of teaching programmes across the borders within Europe.

1. Introduction

Nanoscale science has great potential for applications but the next step, leading to new and useful nanotechnology products, is in general far away. Nanometer structures are today commonly used in the microelectronics industry in commercial integrated circuits. Further shrinking down, following Moores law [1], will eventually require both new fabrication methods and lead to (unwanted) quantum effects. Whether we want to use the new physical effects on the nanoscale, or need to know how to avoid them, we will need engineers with knowledge in nanoscience and nanotechnology. We will need specialists in specific areas like nanofabrication, quantum physics, or nanobiology, as well as new types of engineers and scientists with knowledge in a variety of disciplines, spanning from physics, via electronics, mechanics, chemistry and materials science, to computer science, and further on to molecular and cell biology. One example is the coming together of physics and biology in what we today call bionano- or nanobioscience. Who has not heard physicists start their presentations at conferences with "I am not a microbiologist, but I will do my best in explaining our results" or the microbiologist starting "I am not a physicist but". There is a shortage of individuals with solid knowledge in both fields.

In order to meet the challenges of taking today's nanoscience into tomorrow's nanotechnology, many countries and universities have started undergraduate educational programmes on nanoscience and nanotechnology. But how should these programmes be designed and for whom? What do society and industry need today? What do we need in five, ten, or twenty years?

We must remember that a significant part of the students graduating from nano-master programmes will still go to commercial companies, not working with nanotechnology. The knowledge gained during a nanomaster programme must therefore have a lasting value for a wide-range of foreseen and unforeseen possible developments of nanotechnology outside the university world, as well as a lasting value for those students who will never work with nanotechnology in the future.

The balance between fundamental knowledge, e.g. the physics on the nanoscale, and recent findings and the state of the art, have to be carefully balanced when teaching nanoscience. There should be options for the students to form their individual scientific profile, be it on the fundamental, theoretical or experimental, level of nanoscience. There should also be courses which are not specifically related to nanoscience. To assure high quality, all courses should be given by experts. The above was our vision and starting point when we created the programme Nanoscience and Nanotechnology, EMM-nano [2].

2. The Erasmus Mundus Master (EMM) programme [3]

EMM-nano is run by four European partners: Katholieke Universiteit Leuven, Belgium (co-ordinator), Chalmers University of Technology, Sweden, Technische Universität Dresden, Germany, and Delft University of Technology/Leiden University, The Netherlands. The four partners offer speciality courses in at least two out of four major themes: Nanoscience (NS), Nanotechnology (NT), Biophysics (BP), and Bionanotechnology (BNT). EMM-nano is a two-year, two-location programme.

Trajectories: Each student studies the first year at one partner and the second year at another partner. The students get a double master degree, i.e. they get one master degree from each of the two partners where they have studied. EMM provides EU-funded scholarships for third country (non-EU) nationals participating in these Masters Courses, as well as scholarships for EU-nationals studying at Partner universities throughout the world.

Themes: Within EMM-nano, the themes of the different partners are: KU Leuven (NS, NT); TU Delft/Leiden: (NS, BP); TU Dresden: (BP, BNT); Chalmers: (NS, NT). The eight different trajectories, first year KU Leuven - second year Chalmers, first year TU Delft/Leiden second year KU Leuven, etc., are chosen based on the individual interests of the students. In most cases the students, provided they are admitted to the programme, can follow the trajectory of their choice. In rare cases, e.g. when the academic background of the student seems too far away from the main themes of his/her proposed trajectory, the EMM-board may suggest an alternate trajectory. Alternatively, the EMM-nano Board can directly contact the student to advise him/her to contact the partner coordinator to get dedicated material to study on his/her own before starting the programme. With highly motivated top students this has turned out to work fine. We have not admitted students with a pure biology background as they have too little mathematics and physics (if any) in their Bachelor curricula. Thus the students individually design their master education by choosing the two partners who combined best meet their interests. Further specialization is reached by the choice of elective courses and the master thesis work.

Admission to the EMM-nano programme: When going down to nanometer dimensions, the physical properties of a system change and we may talk about the field of nanophysics. The EMM-nano programme requires that the applicants have a Bachelor of Physics degree or equivalent, but it is important that we also provide education for students with a slightly different background. We have tried to design the programme in a way that also top students

from other disciplines, e.g. electronics and chemistry, with a proven knowledge of physics, can successfully profit from the training in the programme. We generally require a GPA of at least 75% from the students (in their Bachelor degrees) to be admitted to the programme. We have about 100-150 third-country applicants every year and we admit about 35, of which about 25 are awarded an Erasmus Mundus Scholarship by the European Commission and the Erasmus Mundus Programme.

At KU Leuven two-week-long introductory courses are offered to EMM-nano students going to Leuven to facilitate studies in topics where they have only relatively little experience from their Bachelor studies. At Chalmers, Delft/Leiden, and Dresden, the core courses are designed to give a brief introduction to fields new to the students before going to more advanced levels. Our experience from the two first years of running EMM-nano is that the programme is accessible and awarding for students with a wide range of backgrounds, although, the courses generally require a large investment of work from the students. The EMM-nano students generally perform very well, both in single courses and when doing their master theses. The first Master of Science degrees within the programme will be awarded during summer 2007.

The Erasmus Mundus Lecture Series on Nanotechnology in Modern Society: Within the EMM-nano programme we have created a common course in the form of a lecture series, simultaneously followed by all students in the programme. The course is run via videoconferencing, i.e. the lectures are transmitted live to lecture rooms at all the partners. The goals of the series are to provide high level lectures on nanoscience research and ethical aspects of nanotechnology to the EMM-nano students to further increase the integration between students and teachers at and between the four partner universities, to evaluate the concept of E-learning in the form of video-conferencing. The lectures from the two first years have to about 50% been on ethical issues of nanotechnology. EMM-nano also has an active *Scholars* programme.

The EMM-nano spring workshop: We organize an annual workshop for all EMM-nano students where they also meet teachers and administrators from the other partners. They get information about procedures related to master thesis works and graduation, and they share information with each other about the country and partner universities they are going to for the second year. The second-year students make short presentations of their ongoing master thesis projects to the fellow students in the programme.

3. Challenges

Although the EMM-nano programme so far has worked out very well, there have been and are still challenges to be met. Most of these relates to internationalization of education in general, different legislation and tradition, and to the so-called Bologna Process [4]. Others are related to the multidisciplinary nature of the field of nanoscience and nanotechnology.

National vs. common rules: All partners have experience from running international educational programmes on the master level prior to forming the EMM-nano consortium, and have also agreed to follow the Bologna Process with a 3-year Bachelor and a subsequent 2-year Master. But there are still important differences, both in terms of specific national rules for higher education, and in tradition between the universities (e.g. semesters vs quarters, courses spanning over quarters or semesters, different systems for grading, different starts and endings of the studies) that made it natural to use whole academic years as the periods of study at the different partner universities within EMM-nano. The eight possible trajectories provide enough freedom for the students to form their own scientific profile.

Double degree vs. joint degree: The European Commission wants and promotes formation of common rules and joint degrees, for Erasmus Mundus Programmes. But national legislation often make this difficult. We believe that large scale integration of education across European borders will require significant adaptation to common rules in European higher education. Converting to the 3 year Bachelor plus 2 year Master system is the easy part, even if it sometimes

requires major reorganization of programmes and courses. The difficult parts instead relate to the discrepancies in traditions and national legislation in the different countries. Within the EMM-nano consortium we have solved or at least avoided these problems as far as possible by the construction of a two-year, two-location, programme, which complies with the local national education system of the partner during each year, and results in a double masters degree. The master thesis work, performed at the second year university, counts for both degrees. We would however like to be able to award a joint degree for the programme in the future. That would simplify further integration with common courses, and courses with teachers from several partners, increase the mobility of the students and teachers, and give more flexibility in designing the curriculum for the whole programme.

Students in the cleanroom: For almost all types of nanofabrication, cleanroom laboratories with dedicated equipment like e-beam lithography, surface film deposition and patterning techniques, etc. are vital. Whether the students continue with nanotechnology, or go to other high-tech areas after graduation from the EMM-nano programme, they will likely come into close contact with cleanroom processing, or with people working in cleanrooms. They therefore need both theoretical and practical training in cleanroom work and processing. Theoretical courses on micro and nanofrabrication are combined with extensive hands-on work in cleanroom laboratories. At Chalmers, the EMM-nano students are trained in basic cleanroom processing techniques at the department of Microtechnology and Nanoscience (MC2) through compulsory and elective courses. In the compulsory course "Modeling and fabrication of micro and nanodevices" the students work on research topics inside the Chalmers Nanofabrication Laboratory (NFL), a 1000 m^2 cleanroom for micro-, and nanofabrication [5]. In this course the students work under supervision from senior researchers and PhD students. A majority of the students also do extensive work inside the cleanroom during their half-year master thesis project. They go through special training on the equipment they will use during their project, and after obtaining the drivers licenses they are allowed to book the equipment and run the processes on their own inside the cleanroom. The unique educational activities inside the cleanroom would not be possible without the efforts by the cleanroom staff and the researchers and PhD students at MC2. We would like to increase these activities but the high costs in running cleanrooms compared to what the department gets in compensation for educational activities is the limiting factor. We hope that we in the future also can get access to parts of the IMEC cleanroom facilities, the largest in Europe, for hands-on training and project works. However, this is unfortunately not possible today.

4. Conclusions

The EMM-nano is the first Erasmus Mundus Master Programme on nanotechnology. In the two-year, two-location programme the students have large freedom to build their own scientific profile through the choice of trajectory and the different expertise and research activities within nanoscience at the four partners. Our vision is that the programme should give a firm basis for continued activities in the field of nanoscience and nanotechnology, both within research at university and within emerging industry. But at the same time it is important that the students after graduation are attractive also for companies outside the nanotech area.

While the contents is based on what we believe is important for the students to learn, the specific structure of EMM-nano is also governed by external pre-conditions. We aim to further increase the integration across geographical borders. To allow for awarding a joint degree for the whole programme would be a large step in this direction.

[1] International Technology Roadmap for Semiconductors (ITRS); http://www.itrs.net/reports.html
[2] EMM-Nano; http://www.emm-nano.org/
[3] Erasmus Mundus programme; http://ec.europa.eu/education/programmes/mundus/index_en.html
[4] The Bologna Process; http://ec.europa.eu/education/policies/educ/bologna/bologna_en.html
[5] Chalmers/MC2 Nanofabrication Laboratory; http://www.mc2.chalmers.se/nanolab/